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COMPARISON OF JANUS AND FIELD TEST HELICOPTER ENGAGEMENT RANGES FOR THE LINE-OF-SIGHT FORWARD HEAVY SYSTEM

by

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Comparison of Janus and Field Test Helicopter Engagement Ranges for the Line-of-Sight Forward Heavy System

by

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ABSTRACT

This thesis compares helicopter engagement ranges from an operational field test to similar ranges generated by simulation of the test in Janus(A). The purpose is to analyze the feasibility of accrediting the Janus(A) combat model for the Post-Test Modeling Phase of an Army concept called Model-Test-Model. Means and distributions of helicopter engagement ranges are analyzed. The Janus engagement ranges are greater than those of the operational test. No common link between the two tests and the scenarios is apparent. Other issues include time taken to ensure that a credible database is entered in Janus and improvement of terrain and helicopter representation for a more realistic result.

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I. INTRODUCTION

A. GENERAL

The goal of operational testing is to "conduct field testing, under realistic combat conditions, of any item of weapons, equipment, or munitions for the purpose of determining the effectiveness and suitability for use in combat by typical military users" [Ref. 1]. Unfortunately, due to budget constraints and the lack of maneuver area, equipment, troops and time, it may not be feasible to test these items thoroughly. The use of modeling and simulation can help to close the gap when full scale testing is unavailable [Ref. 2:p. 1]. Janus(A) is one of the models used for this purpose.

Comparison between operational field tests and high resolution combat models such as Janus can provide more information to assist test design and possibly extend test procedures. Once a field test has been performed, the data obtained can be used to calibrate the model to the test. Calibration entails making adjustments to input data or model logic to obtain a closer agreement with an external index [Ref. 3:p.5]. If the model proves to be credible, it can be used to extend test results beyond the field test environment, thus saving time and money which would be required to run

further field tests. The Army uses a concept called Model-Test-Model (M-T-M) to implement modeling and simulation in operational testing.

B. THESIS OBJECTIVE

This thesis analyzes the feasibility of accrediting the Janus combat model for the post-test modeling of aircraft engagement ranges. Specifically, helicopter engagement ranges collected from the Line-of-Sight Forward (Heavy) (LOS-F-H) Initial Operational Field Test and Evaluation (IOTE) conducted at Fort Hunter Liggett, California in Spring 1990 are compared to similar ranges generated by simulation of the test in the Janus combat model. Route data collected from the operational test are replicated within Janus so that runs can be made to obtain model engagement ranges. The means and distributions of engagement ranges from both the model and operational test are compared statistically to analyze the feasibility of using the simulation for future post-test modeling of the LOS-F-H system.

C. MODEL ACCREDITATION

Model accreditation is part of the process of validating or establishing credibility of the model. Validation is the "process of determining that a model is an accurate representation of the intended real-world entity from the perspective of the intended use of the model" [Ref. 3:p. 1:

Enclosure 2]. Accreditation is necessary if the model is not fully validated. It is the process of certifying that a model achieved an established standard when applied for a specific purpose [Ref. 2:p. 6]. Models are accredited for particular types of applications since validation is a continuous process and full validation may not be technically or economically feasible. A model is subject to accreditation when it is proposed for use with a new application or system [Ref. 3:p. 3]. In this case, the Janus combat model requires accreditation with the new LOS-F-H system performing helicopter engagements.

D. DEFINITION OF ENGAGEMENT

An engagement is defined as the moment the fire button is pushed on the LOS-F-H system. Of primary interest is the range between the target and the system when engagement occurs. This analysis will be concerned only with the range of first engagement. This is the initial range at which the gunner shoots at a target for the first time. Consecutive shots by the same system on the same target will not be considered. These consecutive shots are assumed to be statistically dependent for the purpose of this thesis. Both Janus and the LOS-F-H data will be edited to provide the range of first engagement.

E. LINE-OF-SIGHT FORWARD (HEAVY) SYSTEM [Ref 4:p. 1-7]

Recently, the Army has proposed a major revision in divisional air defense concept. The Forward Area Air Defense System (FAADS) program integrates five components designed to protect a division from low altitude air threat. One of the primary components in a heavy division is the LOS-F-H air defense system. The LOS-F-H is a surface to air missile system mounted on a modified Bradley fighting vehicle, manned by a crew of three: a commander/radar operator (RO), a gunner/electro-optics (EO) operator, and a driver (Figure 1).

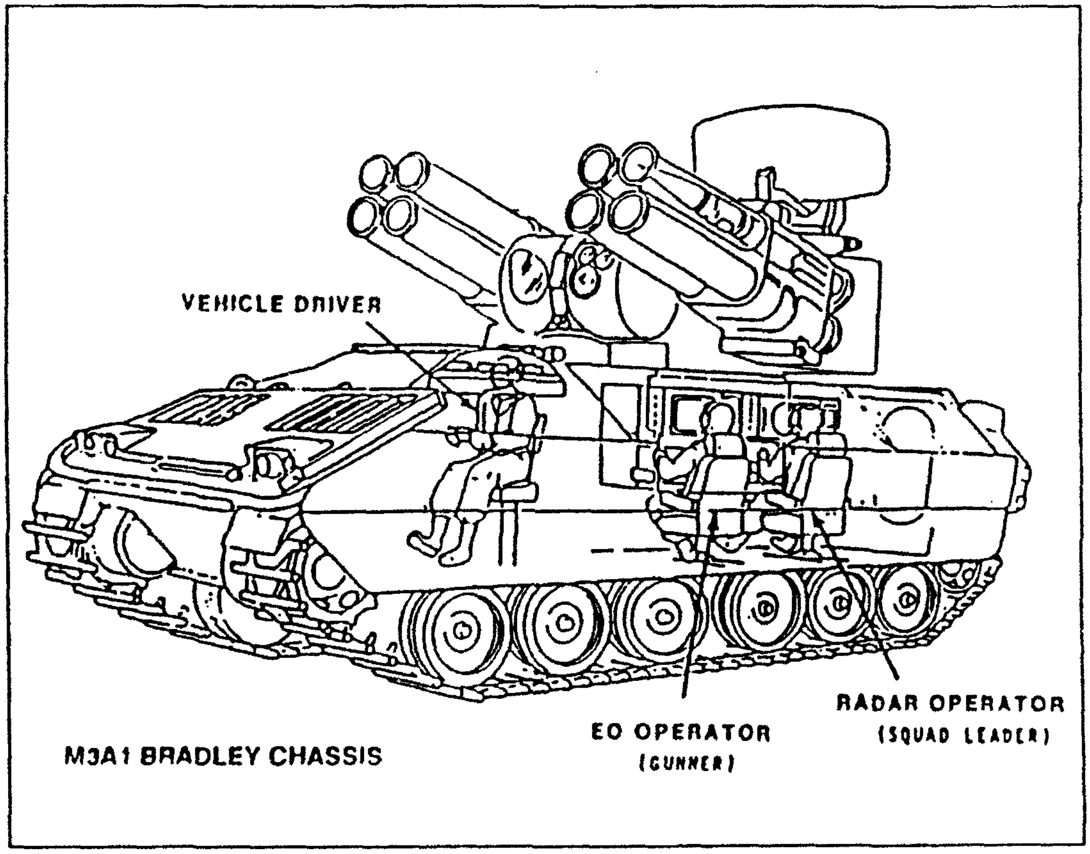

Figure 1 LOS-F-H System

The fire unit has its own acquisition and tracking radar which is capable of tracking several aircraft while scanning for others out to 20 kilometers. The system carries eight missiles which weigh 112 pounds each and are in ready-to-fire canisters. Each missile is a laser beam rider guided by a coded laser beam which minimizes the effects of countermeasure. The unclassified range of the missile is 8 kilometers.

The crew uses a Forward Looking Infrared sensor (FLIR) or an optical (TV) sensor to help identify and track the target. An Identification, Friend or Foe (IFF) device which receives an encrypted transmission sent by friendly aircraft is used to make final identification of an enemy aircraft. The gunner then launches a missile and tracks it to the target.

F. MODEL-TEST-MODEL CONCEPT

There are three phases to the Model-Test-Model (M-T-M) concept: pretest modeling phase, field test and modeling phase, post-test modeling phase [Ref. 5:p.3].

1. Pretest Phase

This phase is designed to assist planners prior to actual operational testing. Selected models exercise possible test scenarios to provide information on the best possible test design. This information includes methods to optimize data collection, minimize test failure and alert testers to the impact of external constraints. The results provide

planners confidence that test objectives can be achieved and provide the modeler important information that can be used with future modeling of the system. This phase can save the designer valuable time which would otherwise be wasted in the field [Ref 6]. Unfortunately, this phase was not conducted prior to the field test for the LOS-F-H.

2. Field Test and Modeling Phase

This phase involves a series of complete field tests to evaluate the new system and model runs to provide rapid analysis and feedback to test personnel. Operational tests are run in order to provide an assessment of how the system characteristics perform in a variety of different operational scenarios. Under the best circumstances, scenarios are *developed in the pre-test phase for use in the initial* operational trials. Field testing is done by military personnel in a series of trials conducted to replicate the use of the system. These trials are usually between two opposing forces. Once a field test is complete the data is passed to the modeler who performs successive iterations of model runs to provide feedback, but most importantly to calibrate the model code and model data [Ref 5]. This involves updating input parameters such as weapon characteristics to field constraints. Actual play positions are used as input to complete the model runs and a comparison analysis is conducted

at the individual event level (i.e. engagements) to determine the possibility of accreditation.

3. Post-Test Modeling

The third and final phase involves the cautious use of the 'calibrated' model in order to extend the test results to conditions, situations and threats not tested in the field [Ref 5]. This 'non-testing' may be due to cost, safety, environmental, equipment or some other type of constraint. During this phase it is important not to extend the model beyond the point at which the calibrated process representations would no longer be valid.

II. OPERATIONAL FIELD TEST

A. BACKGROUND

The operational field test of the LOS-F-H system consisted of fifty maneuver trials. These trials were conducted from 9 April to 23 May 1990. Each trial was a force on force battle which generally lasted one hour. Both day and night trials were performed, as well as trials in MOPP0 and MOPP4 (two variations of Mission Oriented Protective Posture). The battles involved Red and Blue mechanized forces of battalion (minus) strength. Battalion (minus) indicates that only part of the battalion was used. Surrogate aircraft representing the Mi-24 Attack Helicopter (HIND), the Mi-14 Medium Helicopter (HAVOC) and the Mi-8 Medium Helicopter (HIP) supported the Red forces. The LOS-F-H mission was to defend the Blue maneuver force against air attack as the force conducted its mission. Different scenarios were tested with variations in offensive and defensive operations and Blue force orientation.

B. AIRCRAFT PRESENTATION

Tactical and safety controls were provided for all aircraft. Airspace safety control was of primary concern and sometimes dictated flight routes, altitudes and tactics. The maximum altitude above the terrain for all helicopters was 150

feet, but there was no minimum altitude. Helicopters entered the battle area making their approach to the Blue player's front. It was assumed that Blue players received lateral protection from notional units which are units that are not physically on the ground, but are perceived to be there by all players. Aircraft were accounted for in presentations. A presentation began when an aircraft left its holding area to enter battle and ended when it returned to its holding area. If an aircraft was 'killed' during a presentation, it would return to its holding area and would be revived by the controllers and sent into battle as another aircraft. Aircraft were the only players revived during the trial and that occurred only in holding areas [Ref. 4:p.2-22]. Presentations lasted anywhere from 7 to 30 minutes depending on the trial and number of aircraft desired to represent.

C. DATA COLLECTION

Firing information for all weapon types were provided by a laser installed on each firer and by laser sensors on each target. A laser pairing provided the real-time computer with the firer and target identification. This process was called Real-time Casualty Assessment (RTCA). The RTCA consisted of firer and target identification, weapon type, trigger pull time, probability of kill, assessment of shot and time of impact. Video tapes were used inside the LOS-F-H fire unit to record the battle and a Range Measuring System (RMS) recorded

the system location data as well as engagement range information using a form of triangulation [Ref 4].

Several computer reports were generated providing information for analysis. Two of these files, the Player Position Location File (PLS) and the Attack Engagement File (AEF) provided information specifically concerning the LOS-F-H. The PLS file recorded player locations at every second during the battle. This data was used to imitate the actual battle in Janus. The AEF file provided information on the trial engagement segment, specifically the LOS-F-H engagement of aircraft. The data from this file were used for engagement range comparison with the data obtained from the Janus runs.

D. DATA LIMITATIONS

1. Range Measuring System (RMS) Errors

This type of error affected the vehicle and aircraft routes as well as engagement ranges. The RMS at Fort Hunter Liggett records the position data and calculates the engagement range from the position data. Errors due to inaccurate triangulation (spikes) or lost signals (gaps) could provide false location and engagement ranges. Although most of the data was smoothed there was still some error associated with this problem. This error can affect the actual player location as well as the calculated engagement range.

2. Real-Time Casualty Assessment (RTCA) Errors

RTCA missed about 18 percent of the LOS-F-H launches because of low or dead batteries in the laser equipment. Other launches resulted in no laser pairing and therefore provided no target. These launches were reconstructed as closely as possible by analyzing video tape and using player location plots. Over 90 percent of the total launches were evaluated by analyzing video and verifying RTCA results leaving almost ten percent of the RTCA results not verified.

E. DATA SELECTION

Although the test consisted of fifty trials, only five were selected for analysis. The five trials chosen were under identical conditions of daytime, MOPP0, no smoke, Blue in defense and facing northwest. These trials were selected since they provided the most helicopter engagement data (Table 1).

TABLE 1 TRIAL CONDITIONS

LOS-F-H TRIALS SELECTED: 100B, 112B, 122B, 123B, 125B	
FACTOR	**CONDITION**
TIME	DAY
TACTICS	DEFENSE
DIRECTION	NORTHWEST
SMOKE	NONE
CHEMICAL	NONE

III. JANUS

A. BACKGROUND

Janus is an interactive, brigade level, two sided, event driven simulation that models fighting systems as entities (helicopter, tanks, etc.). Entity characteristics include descriptions of weapons carried, weapon capabilities, movement speeds and how they are affected by terrain, ammunition and fuel, crew performance, sensor data and supply/resupply data. The data can be interactively reviewed and changed by the user. As with any simulation an accurate and complete database is crucial to operation and output. There are a large number of interconnections between portions of the database; therefore, altered data in one area may affect the outcome of the simulation. Terrain is depicted with contour lines, vegetation and cities. Each terrain cell has a fifty meter resolution which corresponds to the Defense Mapping Agency elevation, vegetation and cultural feature description. Graphical symbols represent one or more systems and each system can have one or more weapon [Ref 7].

A Night Vision Electro-Optical Laboratory (NVEOL) model is used for detection. Engagement results are then determined using comparison of random number draws to a probability of hit and kill database. An extensive postprocessing procedure

allows for collection of data such as detection and engagements [Ref 8].

B. TEST DATA CONVERSION

The PLS files from the five field trials were converted into appropriate Janus databases to replicate the field trials vehicle and helicopter movement. A FORTRAN program designed by Captain Al East, a former student at the Naval Postgraduate School, was revised to read the PLS data files and arrange the data into a National Training Center (NTC) format [Ref 9]. Another FORTRAN program (INITNTC) written by Mr. Al Kellner, a programmer from TRADOC Analysis Command (TRAC) White Sands Missile Range, was used to convert the NTC format into Janus format. This conversion process creates scenarios that replicate the force structure and vehicle routes of the field trials. At this point the modeler has the option to adjust some input parameters in order to allow the simulation to represent the field trial with greater accuracy.

C. INPUT PARAMETERS

The Janus database was not changed for weapon and system characteristics. The data was previously entered by students at the Naval Postgraduate School in conjunction with thesis work and is assumed to be accurate. Since the altitude of the helicopters in the field trials was not accurately stated in the Test Report [Ref 4], and the analyst was not present,

there is uncertainty in the flight altitudes. To test the sensitivity of altitude change, the helicopters altitude was changed and each trial was run with three different altitude levels: 15, 25, and 35 meters. Therefore, the five Janus trials became fifteen Janus trials. These altitudes were chosen based on the analysts experience as a pilot.

D. DATA COLLECTION

The fifteen Janus trials were each run three times. This was done to provide enough engagement range data for analysis. Each scenario was run interactively at first to insure that the simulation and the entities were behaving properly. The three runs provided a total of 10 to 50 helicopter engagement ranges for each trial. The Janus postprocessor was used after each trial to provide a cumulative list of engagements. This list was manually reviewed to provide only helicopter first round engagements.

E. DATA LIMITATIONS

The PLS files did not account for the repeated presentations of helicopters in the field trial. This created a problem with the converted data. If a helicopter made more than one presentation, the PLS file only showed one long continuous route. This made it necessary to manually generate the aircraft presentations and routes in Janus. Since ninety percent of the helicopter routes were entered manually, there

may be errors in their location. The Janus screen provides ten digit grid coordinates, while the human can not really distinguish to this accuracy. This can cause some error when engagement ranges are determined by Janus. If the location of the aircraft is incorrect then the engagement range will be in error.

IV. ANALYSIS

A. GENERAL

The purpose of this comparison is to determine if the means and distributions of engagements are the same for the field test and Janus. If they are different then a possible trend which could indicate a shift in location or a possible error might be of interest. Samples from the field test consisted of first range engagements from the five trials. Samples from Janus consisted of three runs of each trial for each helicopter altitude 15, 25, and 35 meters. There was a total of 45 runs. The statistical software Statgraphics [Ref 10] was used to conduct the analysis.

B. ALTITUDE SENSITIVITY

Since the actual altitudes flown by the helicopters were not known, it was of interest to see if the altitude adjustment used in Janus would provide sufficient differences to affect the analysis. This sensitivity analysis could help to determine the best set of data for comparison with the field trials. Each scenario was run with the three different helicopter altitudes and the results were compared. Three assumptions were made concerning the Janus data for this analysis. The data was assumed to be normally distributed, each sample is a random sample from its respective population,

and data in each sample are independent of data from the other samples. The medians were then compared using a notched box and whisker plot (Figure 2) and then a One Way Analysis of Variance (ANOVA) was done to test the null hypothesis that the means were equal (Table 2).

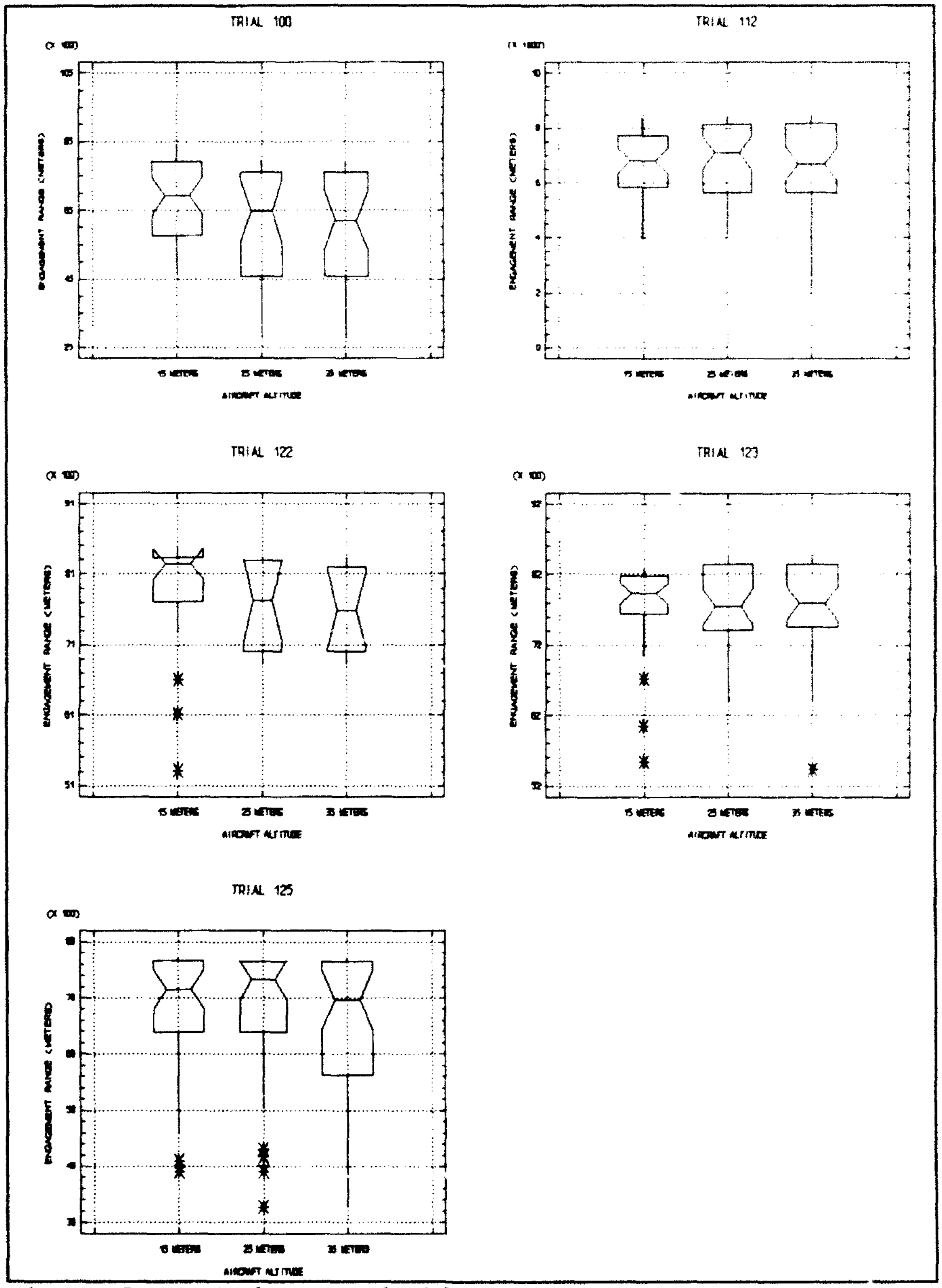

Figure 2 Notched Box and Whisker Plot

TABLE 2 ANOVA VALUES FOR JANUS TRIALS

ANOVA		
TRIAL	**F-RATIO**	**P-VALUE**
100	2.736	*.0700
112	.501	*.6070
122	.351	*.7060
123	.044	*.9566
125	.439	*.6461

The notched box plot provided an approximate 5% test of the null hypothesis that the true medians are equal. Since the notches overlap, we fail to reject the null hypothesis [Ref 11]. With the ANOVA analysis we failed to reject the null hypothesis with a 0.05 significance level. This provides no support for sensitivity to a change in altitude (for these three altitudes) [Ref 12]. For this reason, the central altitude of 25 meters was chosen for use in the continuation. It had the most data points. A summary of statistics for the Janus (25 meter) data and the field data are in Appendix A.

C. ANALYSIS OF NORMALITY [Ref 12]

Both the field data and Janus data were compared to the normal distribution (Figures 3 and 4) via Quantile-Quantile plot.

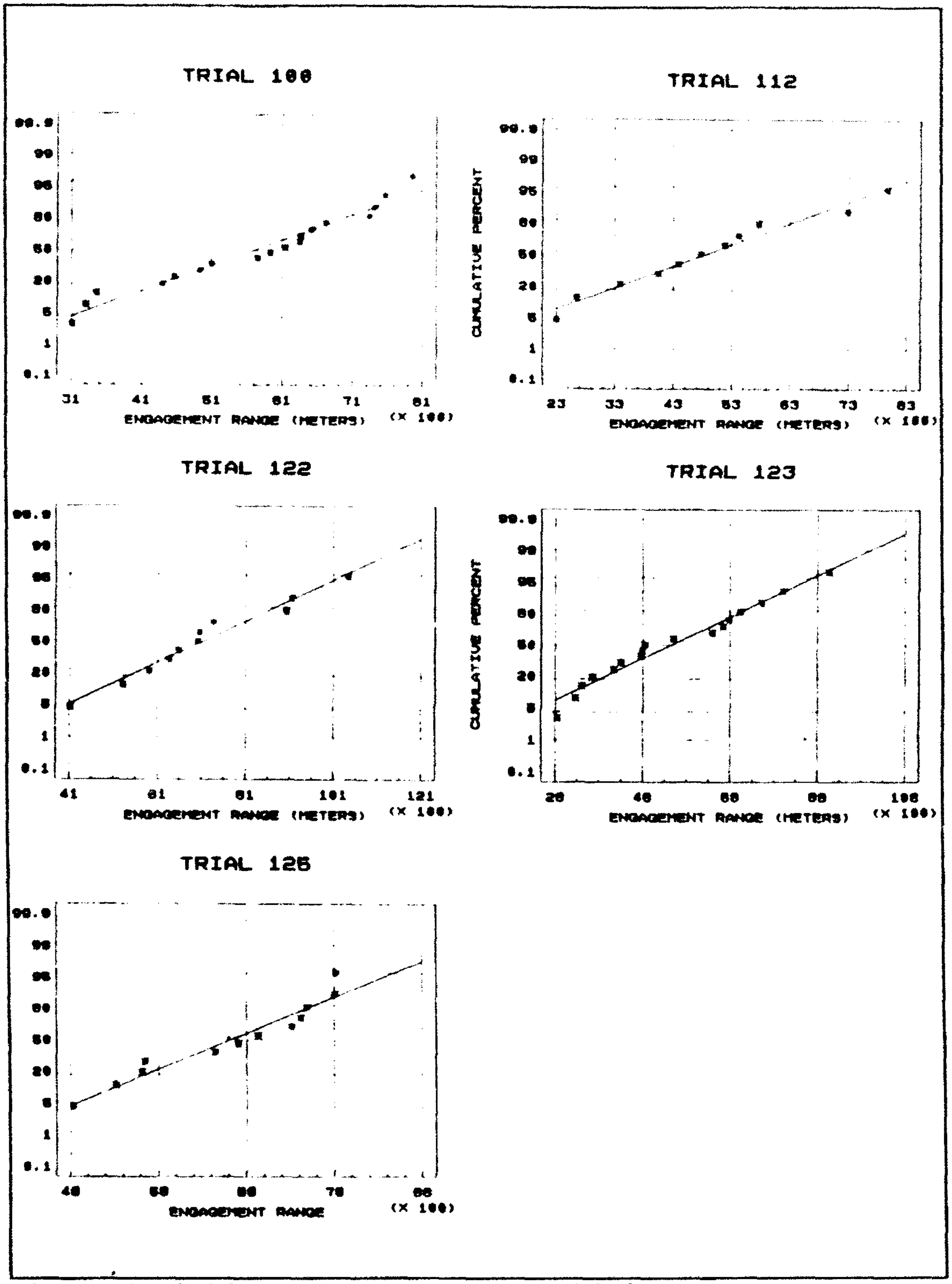

Figure 3 Field Data VS Normal Probability Plot

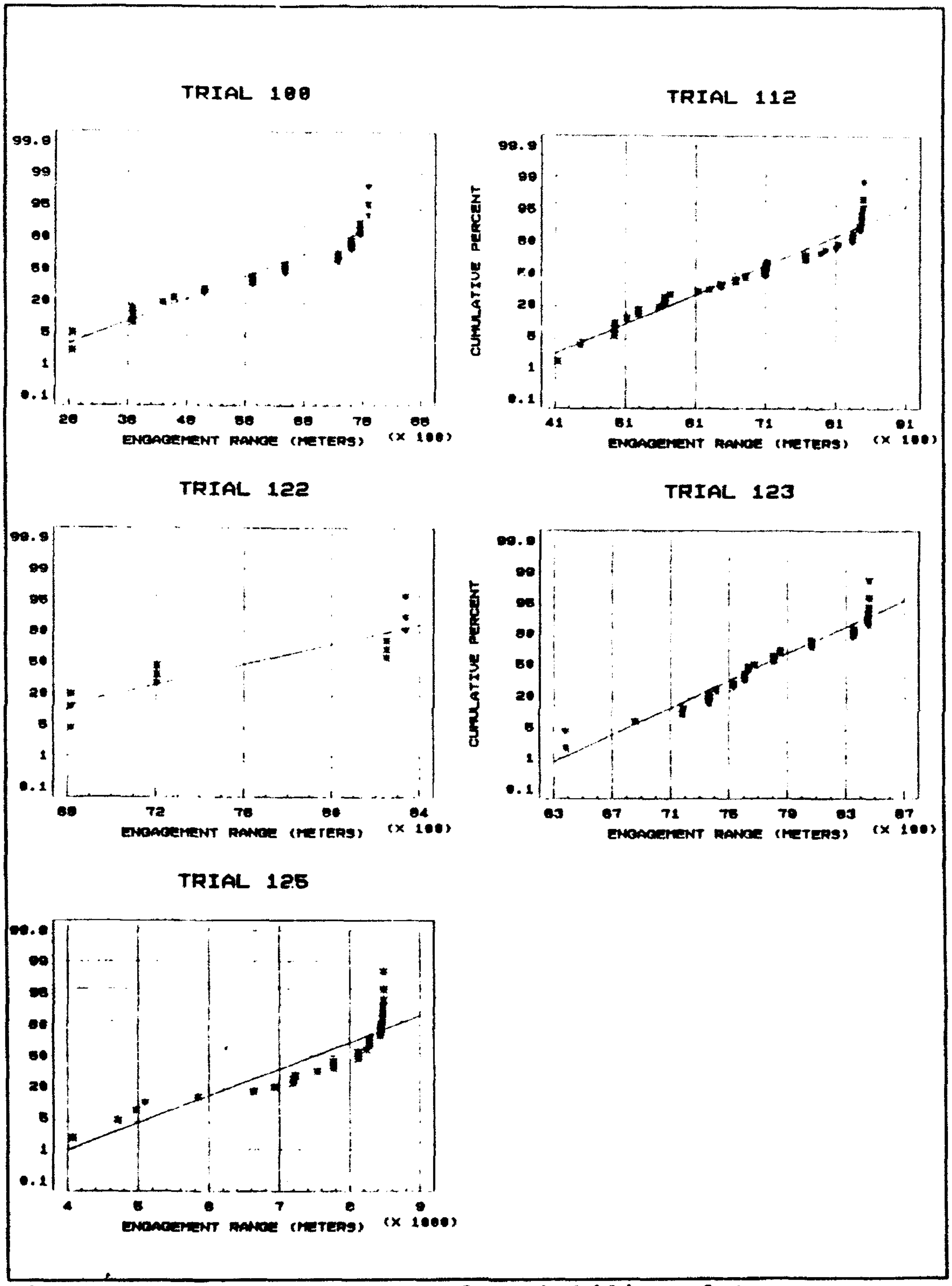

Figure 4 Janus Data VS Normal Probability Plot

The field data appeared close to normal, but the Janus data showed greater deviation. This was especially true at the higher range end of the Janus data. This could be due to the fact that Janus would not engage helicopters beyond the range capability entered in the database. It seems unwise to treat the data as normal because of these deviations from straight lines. A less formal view of the data appears in the Notched Box and Whisker Plot (Figure 5).

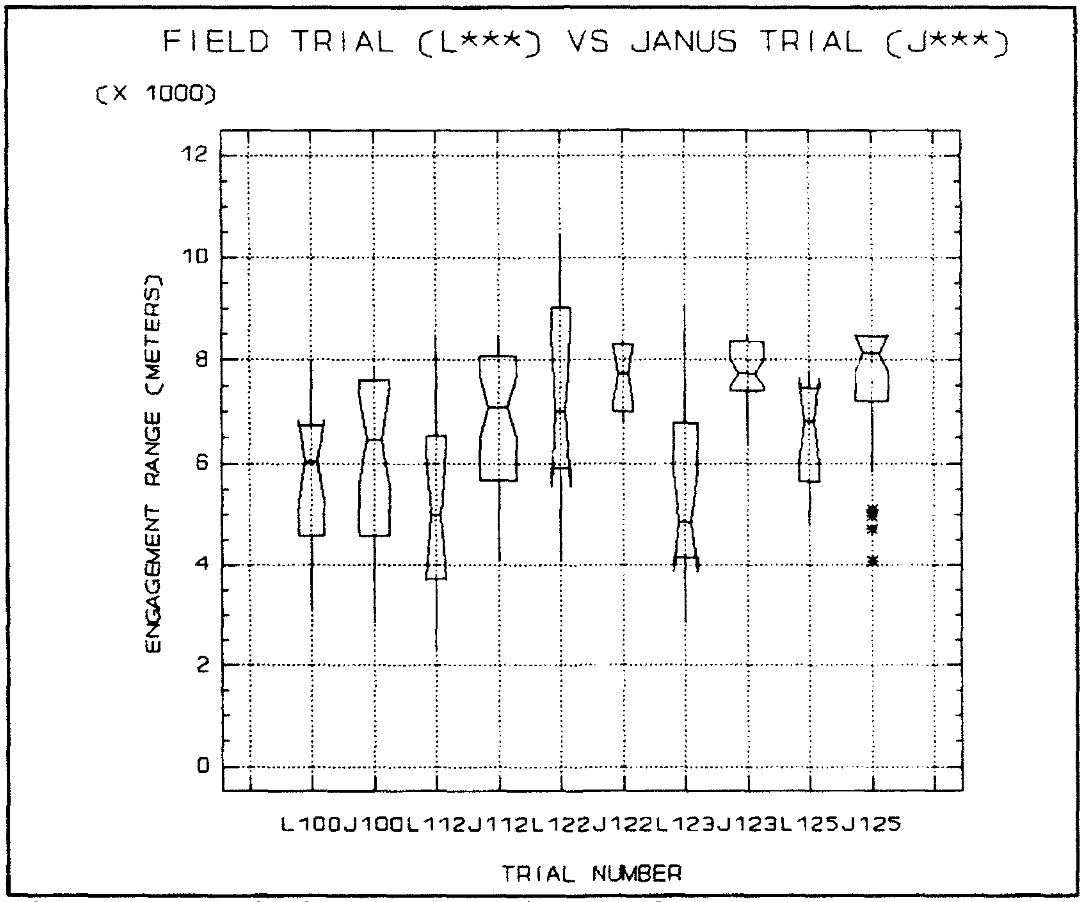

Figure 5 Notched Box and Whisker Plot

This shows at a glance that only two of the trials (100 and 122) appear to have equal medians using a 95% confidence interval.

D. NONPARAMETRIC ANALYSIS [Ref 13]

Nonparametric analysis was conducted since the field and Janus data could not be supported by the normal distribution. The assumption that the data was Independently Identically Distributed was made pertaining to the following tests. Both the Kruskal-Wallis and Mann Whitney test were used to test the null hypothesis that the means are equal (Table 3).

TABLE 3 KW/MW P-VALUES

TRIAL	**KRUSKAL-WALLIS**	**MANN WHITNEY**
	P-VALUE	P-VALUE
100	*.28606	*.29133
112	.00131	.00136
122	*.26604	*.27954
123	.00001	.00001
125	.00927	.00964

The table again indicates that trial 100 and 122 fail to reject the null hypothesis with a 0.05 significance level. These results agree with the results found using the t-test and ANOVA.

The two distributions were then compared using the Kolmogorov-Smirnov Two-Sample Test (Table 4). This test was used to test the null hypothesis that the distributions were the same.

TABLE 4 KS TWO-SAMPLE TEST VALUES

TRIAL	KS TWO-SAMPLE TEST	
	Test Statistic	P-Value
100	.2777	*.3752
112	.5412	.0118
122	.4545	*.1865
123	.7352	.000009
125	.5483	.01099

We fail to reject the null hypothesis with a 0.05 significance level for only two trials 100 and 122. This provides additional support for the previous results.

E. FURTHER ANALYSIS

The above analysis gives us the notion that some, but not all, Janus runs are comparable to the field trials. Let us search for a possible trend that may indicate the reason.

1. Trimmed Sample

Janus trial 125 has the most outliers (Figure 5), so this trial was chosen for application of a t-test with trimmed data. It is possible that some extreme points in the Janus data were influencing the mean and distribution to shift, and

therefore leading to the rejection of the null hypothesis. A 10% trimmed sample was compared to the field data with the null hypothesis that the trimmed mean equals the field data mean. The result was hand calculated and a p-value of .00234 was determined. This shows that even if the Janus data was trimmed the result remains to reject the null hypothesis with a 0.05 significance level.

2. Quantile-Quantile/Regression Analysis

Another attempt to compare the distributions was done using a quantile-quantile plot for both the engagement range and time. The plot was computed based on interpolated quantile values for the Janus data [Ref 10:p. 55]. This gives us the ability to look at the specific difference in each distribution and for possible trend behavior (Figure 6 and 7).

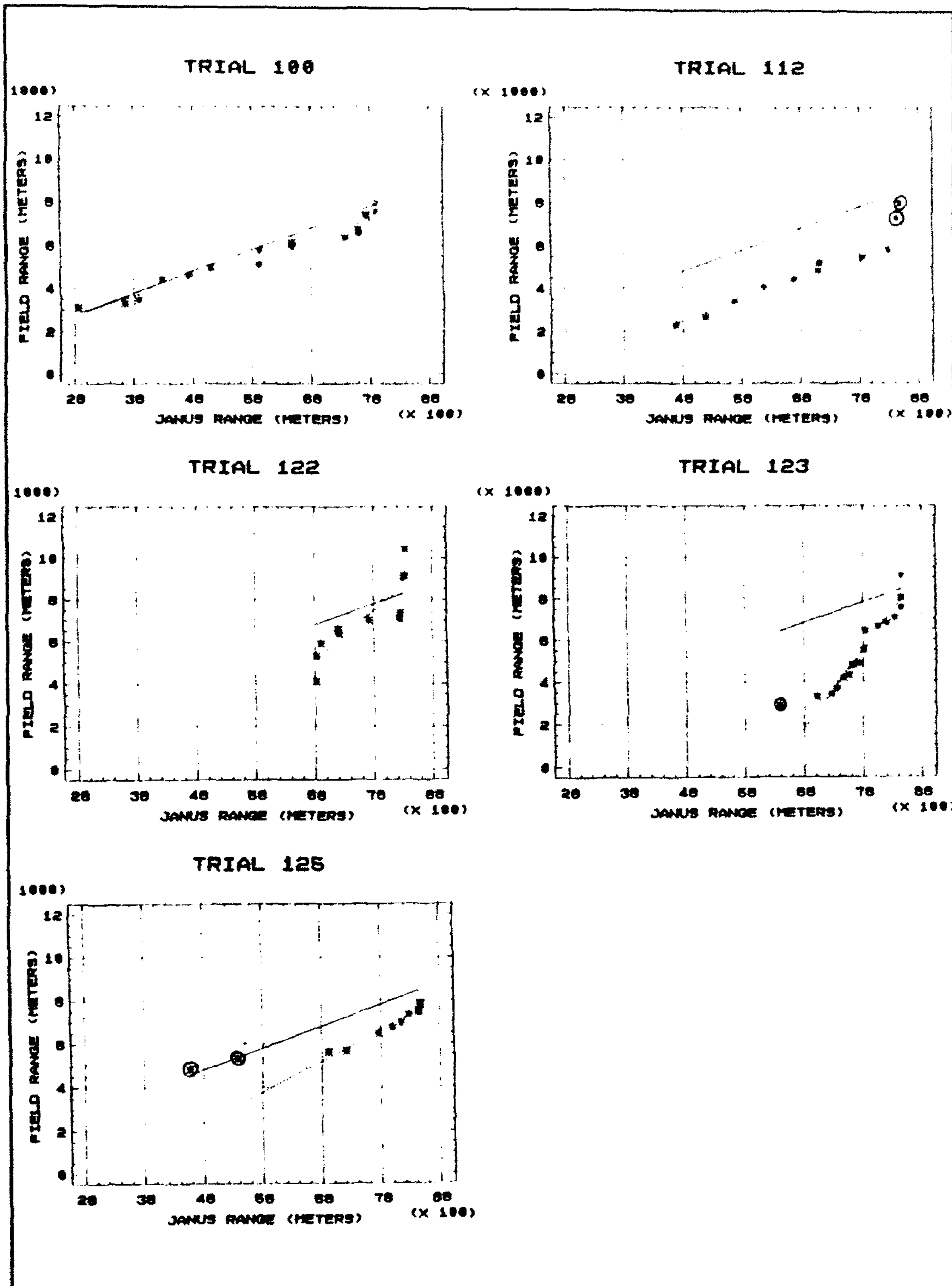

Figure 6 Quantile-Quantile Plot of Ranges

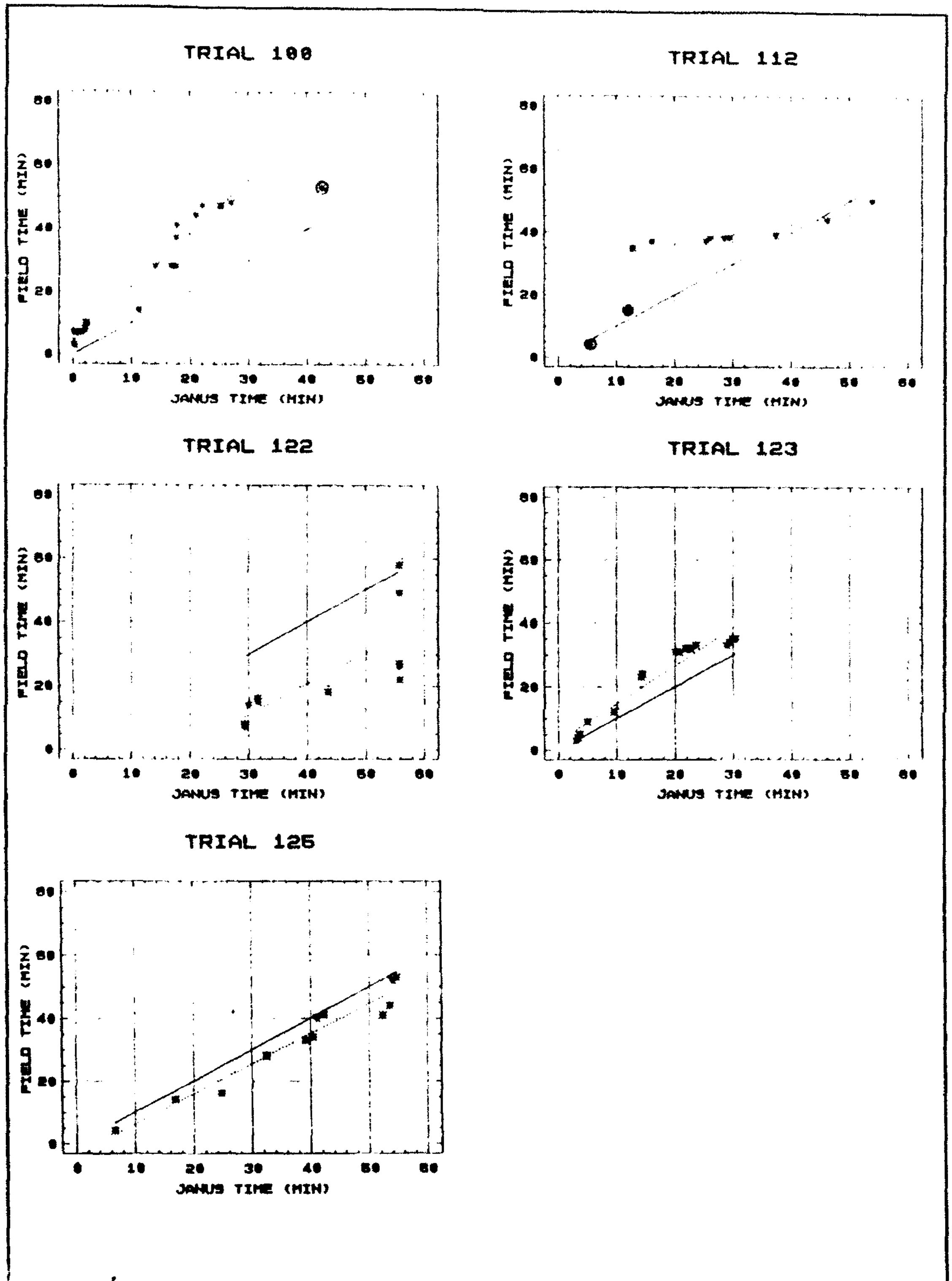

Figure 7 Quantile-Quantile Plot of Times

The solid line is the x=y line. If the distributions were the same, the points would fall on this line. If the distributions are different and some trend is determined, scaling laws can be developed which would allow Janus data to be converted to determine field trial outcomes.

The data points were then fitted with a simple regression line with some extreme points disregarded [Ref 14]. The dotted line on the graph represents this regression line and the circled points are the ones selected to be disregarded when formulating the regression equation. The regression data (Table 5) was computed based on:

Q_{X1} - Janus Quantile Engagement Range Data
Q_{X2} - Janus Quantile Time Data

Q_{Y1} - Field Quantile Engagement Range Data
Q_{Y2} - Field Quantile Time Data

$$Q_{Y1} = a_1 + b_1 Q_{X1}$$

$$Q_{Y2} = a_2 + b_2 Q_{X2}$$

TABLE 5 REGRESSION DATA

TRIAL	a_1	b_1	a_2	b_2
100	343.49	.87595	4.2951	1.7012
112	-2331.2	1.0036	29.744	.32037
122	-11003	2.3684	-17.774	.96152
123	-23656	3.7393	2.791	1.1883
125	-4418.1	1.414	-3.2635	.95837

There does not appear to be any trend or similarities in any of the quantile plots. Each regression equation varies dramatically indicating a difference due to scenario change. Some seem to be merely a shift in location, while others have a completely different distribution. There does not appear to be one specific transformation that could convert the Janus data to the results seen in the field. In other words, the scaling laws appear to be scenario dependent.

3. Predicted Values Comparison

A final attempt to find some link between the Janus output and the field trial was done using the simple regression equations formulated from the Q-Q plot. The raw data from the Janus trials was used to find predicted values for the field trial. The purpose was to seek a correlation between time of engagement and its range. Such a correlation might help connect the scenarios and the scaling laws. The scatterplots are displayed in Figure 8. There appears to be no pattern in these graphs, again giving us no specific link from Janus to the field environment.

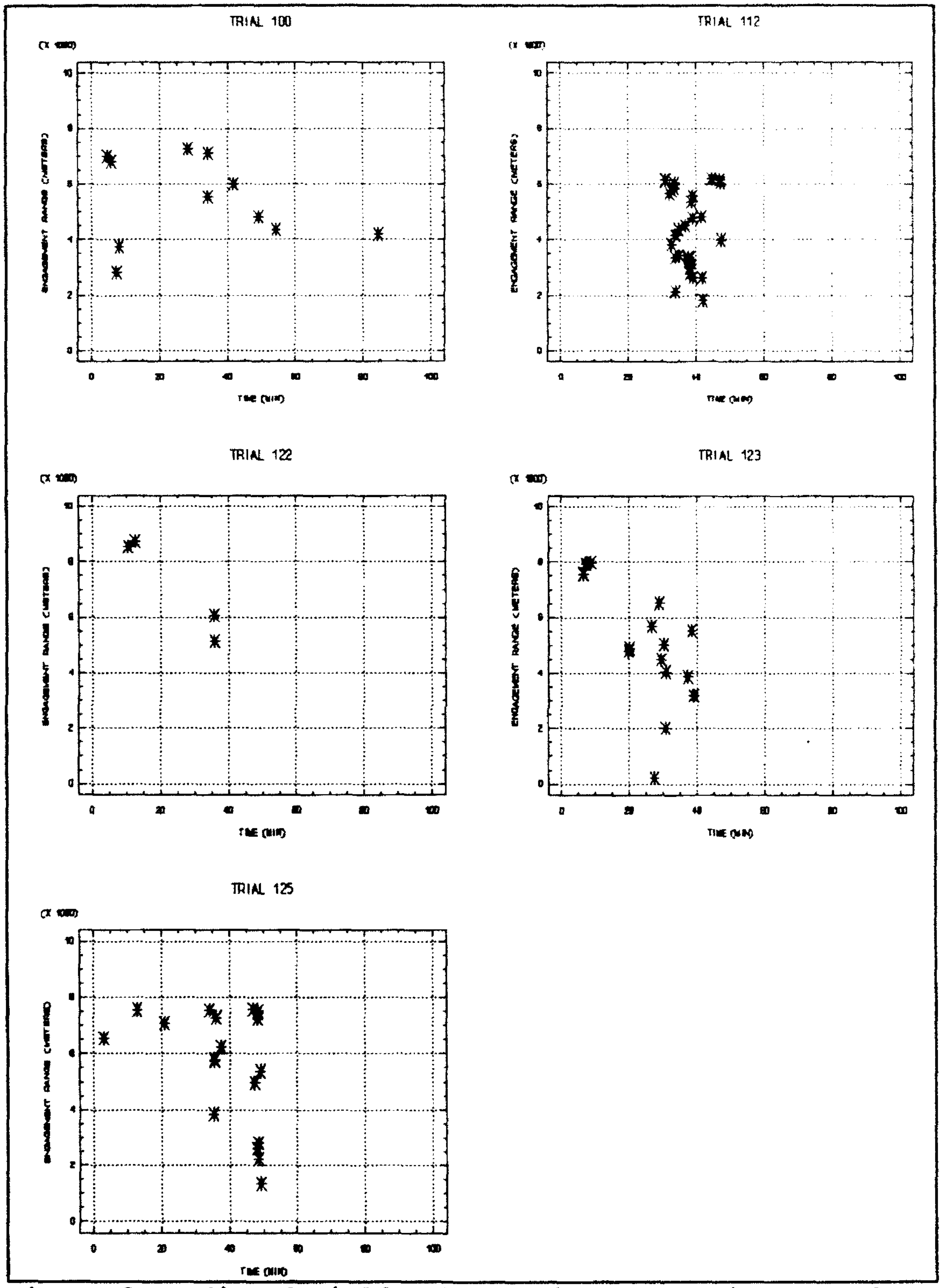

Figure 8 Predicted Field Values Using Regression Equations

V. CONCLUSIONS/RECOMMENDATIONS

A. CONCLUSIONS

At this time, Janus should not be accredited for post-test modeling of helicopter engagements by the LOS-F-H. In three of the five scenarios analyzed, significant differences exist between Janus and the field trial helicopter engagement ranges. Janus mean engagement ranges were higher in all five cases (Appendix A). This indicates that Janus had the Line of Sight (LOS) and was engaging targets prior to the actual field trial. Several reasons are offered for interpretation.

1. The terrain database used in Janus has a fifty meter resolution. Because of this, many lone trees, small rolling hills and other obstacles are not replicated. These obstacles may make some difference in the LOS for the field trials.

2. Most of the helicopter routes were entered into Janus manually. A slight inaccuracy in the route data could result in a helicopter being exposed in the Janus scenario while it was not in the field scenario.

3. The Janus database was assumed to be correct. If some parameters were inaccurate it can affect the performance of the system by either increasing or decreasing its ability.

4. The actual helicopter altitude was unknown since the analyst was not present at the field trial and the after action report only indicated a maximum altitude. The analyst used her experience and judgement to determine the helicopter altitude used in Janus. The three altitudes tested showed no sensitivity, but if a lower altitude was analyzed, this may not be the case.

5. The Janus simulation will always fire at its first opportunity. This may not be the case in the field environment. Personnel in the operational test may not have always fired at their first opportunity. This may be due to several reasons which can be analyzed further, but are not in the scope of this thesis.

The data collection limitations in the field test were minor and the analyst does not believe that they affected the results.

B. RECOMMENDATIONS

In the future, if the Model-Test-Model concept is to be integrated, modelers must be present through the entire test sequence. This will ensure appropriate interaction between the field test and model. The modeler will have no unanswered questions about aircraft altitude or other field trial specifics and can ensure that the appropriate data is being supplied by the field test. This will also test the models data base to ensure the systems are being represented accurately in the model.

More analysis should be done on the Janus terrain database. Fifty meter resolution does not provide enough accuracy to replicate the field test. Future studies and analysis using higher terrain resolution is suggested.

Although this analysis could not accredit the Janus model for modeling of helicopter engagements by LOS-F-H, the analyst believes that with the appropriate database and involvement the results would improve.

APPENDIX A

FIELD TRIALS					
TRIAL	100	112	122	123	125
SIZE	18	11	11	17	12
AVERAGE	5719.11	4835.73	7119	5469.41	6611.75
MEDIAN	6040	4786	7011	4849	6819
STD DEV	1505.11	1769.65	1828.74	1835.4	1031.94
MIN	3106	2301	4119	2858	4828
MAX	7954	7975	10426	9065	7816
RANGE	4848	5674	6307	6207	2988
JANUS TRIALS					
TRIAL	100	112	122	123	125
SIZE	27	43	12	34	31
AVERAGE	6128.44	6858.16	7652.75	7747.26	7509.52
MEDIAN	6472	7094	7729	7740.5	8125
STD DEV	1675.81	1317.79	684.677	559.393	1275.37
MIN	2848	4133	6818	6382	4069
MAX	7889	8489	8335	8458	8478
RANGE	5041	4356	1517	2076	4409

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